WRI-05-P012

CONVERSION OF WESTERN U.S. COALS FOR SEQUESTRATION-READY POWER SYSTEMS (Combustion and Conversion Technologies for Western U.S. Coals)

FINAL REPORT FOR BASE TASK 1.5
Under DE-FC26-98FT40322

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By
Western Research Institute
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DISCLAIMER

ABSTRACT

This project proposes to develop and test schemes for the direct utilization of western U.S. coals in advanced power systems. One of the major issues facing such utilization of coal is the arrival of vapor-phase ash constituents that can cause fouling and hot corrosion of gas path components. The utilization schemes being developed and tested rely on the fact that western U.S. coals can be "partially" gasified at relatively low temperatures, and that the concomitant char produced is reactive. These characteristics afford western U.S. coals a significant advantage over bituminous coals and solid waste fuels such as petroleum coke.

As part of this project, over the past four years, WRI has constructed and tested a fuel-flexible gasifier. The four-inch diameter, fluidized-bed gasifier was designed to be operated as an air-blown, enriched air-blown, oxygen-blown, or as a steam pyrolysis unit. During the past year, the fluidized-bed gasification unit was modified for oxygen-blown operation. Specifically, steam and oxygen delivery systems were installed to allow steam/O_2 mixtures to be used in place of air, and gasification tests were performed with steam/O_2 as the fluidizing medium. The primary goal was to characterize the synthesis gas and char products for oxygen-blown conditions.

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EXECUTIVE SUMMARY

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A series of cold-flow fluidization tests was performed with a bed of Wyodak coal in the 1/16”-1/8”size range. Observation of the bed allowed the fluidization regime to be determined for ambient pressure, ambient temperature operation. Hot-flow tests were performed at 1200°F to assess the fluidization behavior at temperature. Analysis of the syngas product allowed an optimum air/coal ratio to be identified.

The gasifier was then operated at higher temperatures to assess the effect on Syngas composition. Typical gasifier parameters and syngas compositions are given.

BACKGROUND

Gasification-based systems can provide high efficiency with near zero pollutants, resulting in a stable, affordable energy supply for the United States. Gasification technologies provide flexibility in the production of a wide range of products including electricity, fuels, chemicals, hydrogen, and steam. Furthermore, in a time of electricity-and fuel-price spikes, flexible gasification systems provide for operation on low-cost, widely available feed-stocks. The proposed project supports the development of technology for integrated energy plants that will result in the deployment of ultra-clean plants that produce electricity and, where it makes economic sense, "opportunity" products, including clean transportation fuels, high-value chemicals, synthesis gas, and hydrogen, in concurrence with the USDOE Vision 21 Program.

This project proposes to develop and test schemes for the direct utilization of western U.S. coals in advanced power systems. One of the major issues facing such utilization of coal is the arrival of vapor-phase ash constituents that can cause fouling and hot corrosion of gas path components. The utilization schemes being developed and tested rely on the fact that western U.S. coals can be "partially" gasified at relatively low temperatures, and that the concomitant char produced is reactive. These characteristics afford western U.S. coals a significant advantage over bituminous coals and solid waste fuels such as petroleum coke.

As an example (see Figure 1), if a coal can be subjected to partial gasification to produce a low-or medium-Btu gas at temperatures lower than those where alkali present in the coal can volatilize as chlorides, and similarly, the char can be combusted such that alkali compounds are not in vapor phase as sulfates, then in a topping cycle configuration, the desired turbine inlet temperature can be achieved without alkali-based contaminants ever being present in the system in a vapor phase. A near-term application would entail the use of the fuel gas and char in a solid-fuel-fired gas turbine, such as the PGI (Power Generating, Inc.) system. In an alternate, longer-term application, the cleaned fuel gas could be envisaged for use in a solid oxide fuel cell, or fuel cell/gas turbine hybrid system.

Most power generation concepts proposed for the future include capabilities for carbon dioxide capture and sequestration. One technique to remove CO_2 is to operate the combustion and gasification units with O_2/steam or O_2/CO_2 rather than air. This will produce a CO_2-rich flue gas that will require minimal processing prior to CO_2 compression and delivery to a sequestration site. A partial gasification unit, such as the one depicted in the Figure, could quite readily be installed in such an advanced system if O_2/steam or O_2/CO_2 were to be used as the gasifier fluidizing media. Also, control of the O_2: diluent ratio will allow for independent control of 1) the oxygen (hence coal) mass flow rates, and 2) the gas velocity through the fluidized bed. To this end, the emphasis of Task 1.5 was redirected towards CO_2 sequestration-ready configurations, in which the coal is gasified with oxygen/steam rather than air.

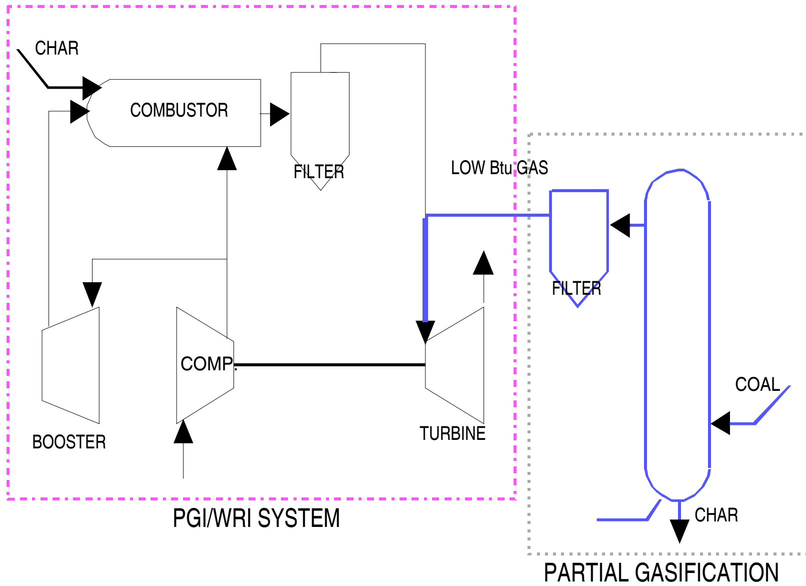

Figure 1.Gasifier Combustion System

OBJECTIVES

The objective of the work was to characterize the synthesis gas and concomitant char products resulting from mild gasification of western U.S. coals. The overall goal was to define processing and utilization conditions such that alkali liberation and liberation of other contaminants are minimized. These conditions were to be defined both for conventional air-blown mild gasification and for operation with O_2/steam. In addition, the syngas products were assessed for their suitability as potential fuel gas in solid oxide fuel cell systems.

RESULTS AND DISCUSSION

As part of this project, over the past four years, WRI has constructed and tested a fuel-flexible gasifier. The four-inch diameter, fluidized-bed gasifier was designed to be operated as an air-blown, enriched air-blown, oxygen-blown, or as a steam pyrolysis unit. During the past year, the fluidized-bed gasification unit was modified for oxygen-blown operation. Specifically, steam and oxygen delivery systems were installed to allow steam/O_2 mixtures to be used in place of air, and gasification tests were performed with steam/O_2 as the fluidizing medium. The primary goal was to characterize the synthesis gas and char products for oxygen-blown conditions.

Results of these tests, namely syngas compositions and heating values, have been encouraging. All tests were performed at or close to ambient pressure. It is still necessary to conduct tests at higher pressures (up to 50psig), pressures for which the unit was originally designed. Also, reliable and consistent operation of the gasifier over long periods needs to be demonstrated.

Initially a series of cold-flow fluidization tests was performed with a bed of Wyodak coal in the 1/16”-1/8”size range. Observation of the bed allowed the fluidization regime to be determined for ambient pressure, ambient temperature operation. Hot-flow tests were performed at 1200°F to assess the fluidization behavior at temperature. Analysis of the syngas product allowed an optimum air/coal ratio to be identified.

Shakedown tests were performed with oxygen/steam mixtures, at a bed temperature of 1200°F. In each of these tests, a stable fluidized bed was attained with air as the fluidizing/oxidizing gas; then the air stream was gradually replaced with a superheated steam/oxygen mixture. A sample analysis of the synthesis gas product appears in Table I below.

Gasifier Operating Conditions	
Temperature	1200°F
Pressure	12 psia
Coal flow rate	15 lb/hr
Syngas Composition (vol %)	
H_2	36%
CO	7%
CO_2	31%
CH_4	3%
N_2	21%

Table I. Gasifer Operating Conditions and Resulting Syngas Composition for a 1200°F Steam/Oxygen Test

In these tests, a small stream of air was left flowing through the propane burner to prevent backflow of steam. This introduced nitrogen into the system, resulting in the relatively high N_2 levels in the syngas. The high H_2:CO ratio of the syngas may have been due to water-gas shift conversion of CO and H_2O to H_2 and CO_2. This reaction would have been promoted by, the high steam concentrations and the relatively low gasification temperatures.

Early tests performed were preliminary in nature, and focused on relatively low temperatures (~1200°F). The gasifier was then operated at higher temperatures to assess the effect on syngas composition. A summary of these steam/O_2 tests appears in Table II below.

Coal Feed Rate	10-30 lb/hr
Bed temperature	1200-1450°F
Reactor pressure	0-5psig

Table II. Summary of gasifier operating conditions for Q4 2003

A typical syngas composition from tests performed at the temperature range of 1400-1450°F appears in Table III below.

Species	Vol % (dry basis)
H_2	36%
CO	27%
CO_2	24%
CH_4	3%
N_2	6%

Table III. Representative synthesis gas composition from O_2/steam tests (1400-1450°F)

Figure 2 depicts the concentrations of the three major syngas species, namely H_2, CO, and CO_2, as a function of bed temperature. The plot indicates that increasing the temperature has the effect of increasing CO and reducing CO_2. This was attributed to the influence of the water gas shift reaction. This reaction is equilibrium limited and favors conversion of CO and H_2O to CO_2 and H_2 at lower temperatures.

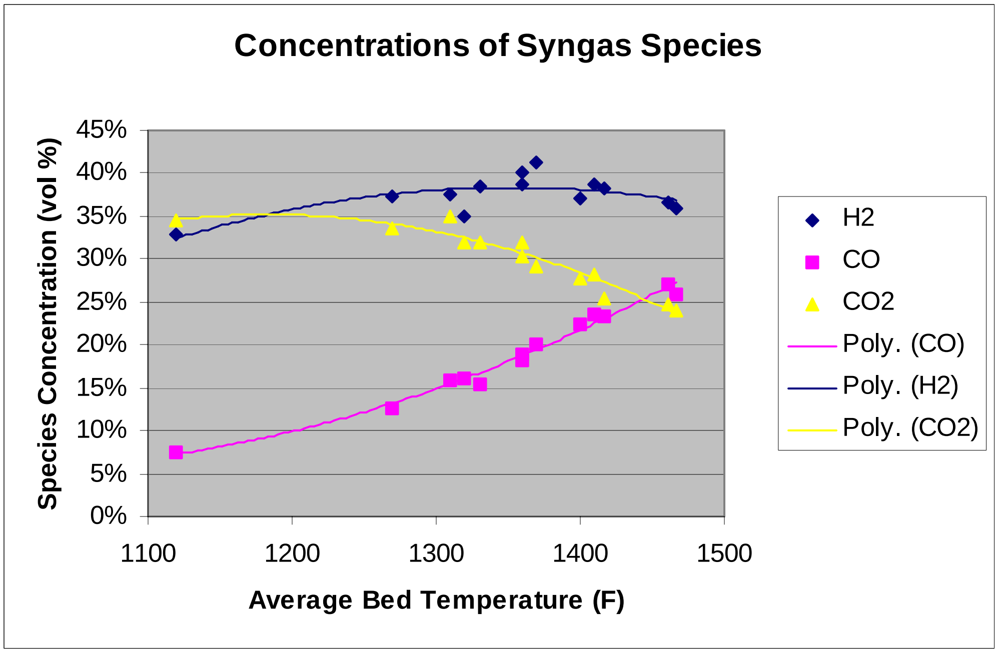

Figure 2. Syngas composition as a function of bed temperature

A number of modifications were made to the gasification facility. Earlier testing had indicated that the steam flowmeter could not yield accurate flow rate data. A smaller flowmeter was subsequently installed and tested. It was shown to improve control and monitoring of the steam flow. Also, a flare was installed on the discharge line. The flare utilizes a propane / air premixed burner to combust the synthesis gas discharge.

It was decided to relocate the backpressure control valve that is used to control the gasifier pressure during high-pressure operation. It was found that this control valve is subject to plugging by tars and coal fines, rendering the valve inoperable. In future high-pressure tests, the synthesis gas will be cooled and filtered upstream of the control valve, minimizing the plugging problem.

A series of long-duration (6-8 hour) tests was performed to determine the long-term operability of the gasifier and to test the syngas slipstream conditioning system (comprising a condenser, filter, and vacuum pump). Testing indicated that longer-term operation resulted in the accumulation of coal fines along the main discharge line; and in the syngas slipstream lines, condenser, and filter. Post-run inspections revealed that the cyclone was undersized for sustained operation. For runs lasting more than 3-4 hours, coal fines would overflow the cyclone and accumulate in the downstream lines. This problem was addressed by installing a large collection drum immediately underneath the cyclone. In addition, a larger dual-filter unit was inserted in the syngas slipstream line. With the collection drum and dual-filter unit in place, the gasifier could be operated for 8 hours or longer without any involuntary shutdowns.

CONCLUSIONS

- As part of this project, over the past four years, WRI has constructed and tested a fuel-flexible gasifier. The four-inch diameter, fluidized-bed gasifier was designed to be operated as an air-blown, enriched air-blown, oxygen-blown, or as a steam pyrolysis unit.

- Shakedown tests were performed with oxygen/steam mixtures, at a bed temperature of 1200°F. In each of these tests, a stable fluidized bed was attained with air as the fluidizing/oxidizing gas.

- The concentrations of the three major syngas species, namely H_2, CO, and CO_2, as a function of bed temperature indicated that increasing the temperature had the effect of increasing carbon monoxide and reducing carbon dioxide.

- A series of long-duration (6-8 hour) tests was performed to determine the long-term operability of the gasifier and to test the syngas slipstream conditioning system.

- Results of these tests, namely syngas compositions and heating values, have been encouraging. All tests were performed at or close to ambient pressure. It is still necessary to conduct tests at higher pressures (up to 50psig), pressures for which the unit was originally designed.